A Brief History of Ozone-Monitoring Satellites and Instruments

Garry Toth and Don Hillger

The following article receiving its first publication here has been reviewed by eminent ozone scientist Dr Arlin Krueger who worked for NASA for many years.

Ozone (O_3), a molecule composed of three oxygen atoms, is found in trace amounts in the stratosphere, with a maximum concentration at about 25 km. It has an important role in protecting life on Earth by screening out most of the harmful solar ultraviolet (UV) radiation (UV-b and UV-c) before it reaches the surface. The Swiss physicist C. F. Schönbein (1799-1868) (Switzerland *Scott* 1060, from 1999) isolated the gas in 1840 and named it ozone, from the Greek *ozein* (to smell), because of its pungent odour. The first ground-based instrument for measuring the total ozone in an atmospheric column was developed by the English physicist G. M. B. Dobson (1889-1976) in 1924. It became known as the Dobson spectrophotometer (British Antarctic Territory *Scott* 177, from 1991) and served as the standard instrument for many decades. The German physicist Erich Regener (1881-1955) (Germany cancel, from 2000) was the first to make *in-situ* upper-level measurements. In 1934 he used a stratospheric balloon with instruments that directly measured the UV absorption by ozone.

With the advent of Earth-orbiting satellites in the late 1950s and 1960s, new possibilities in ozone research opened up. The photochemistry of ozone was poorly understood due to large uncertainties in chemical reaction rate data. In 1977, D. Heath, P. Crutzen, and A. Krueger, in an article in *Science*, used satellite ozone data to demonstrate that nitric oxide produced in a solar proton event catalytically destroyed stratospheric ozone. This opened the door for the theory that other catalysts, like halogens, could modify ozone. In the 1970s, Mario Molina (1943-present) (Mexico *Scott* 2060, from 1997) and his colleagues sounded warning bells about the damage to ozone that they felt was likely being caused by manmade chlorofluorocarbons (CFCs). This theory was supported by the discovery in the mid-1980s by scientists of the British Antarctic Survey using the Dobson spectrophotometer that springtime ozone amounts over Antarctica were much lower than they had been a decade previously. Observations from satellites would soon confirm, in dramatic visual fashion, the existence of the so-called Antarctic ozone "hole". Crutzen, Molina, and F. S. Rowland were jointly awarded the Nobel Prize in chemistry for their work in 1995.

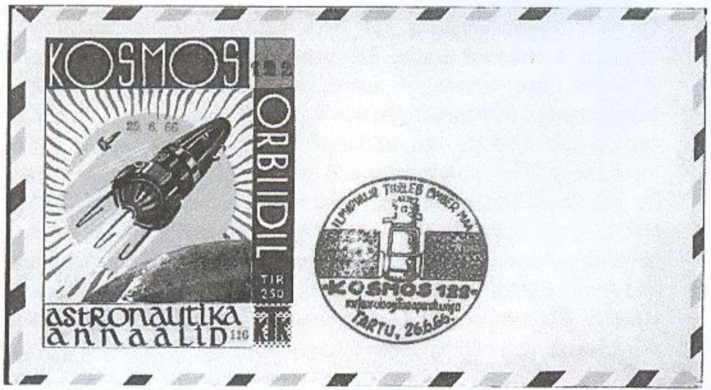
The first remote sensing techniques to observe ozone were developed in the early 1960s. They measured the ozone-induced absorption in the appropriate UV wavelengths in light that had passed through the atmosphere, and compared the result to measurements in nearby wavelengths not absorbed by ozone. Greater absorption meant more ozone, but the details were tricky. One method was to fly UV detectors on balloons (H. Paetzold) and rockets (A. Krueger) to measure extinction of sunlight versus altitude. Another was to use the solar occultation technique: at sunrise (or sunset) a satellite-mounted reflector or sensor would sample sunlight that had grazed the Earth's "limb" (the boundary between its edge and the blackness of space) and so had passed twice through the whole atmospheric column on its way to the detector. Starlight occultation could be used in the same way.

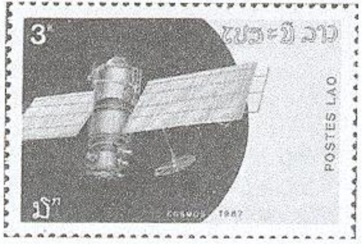
The earliest satellite ozone experiment was passive: no instrument was flown. Instead, visible sunlight in ozone's Chappuis absorption band that grazed the Earth's limb was reflected to ground instruments by the communications satellite Echo-1 (1960 launch; e.g. United States *Scott* 1173, from 1960). It was nothing more than a large aluminized balloon in space designed to reflect radio waves. The experiment demonstrated the Earth satellite occultation principle (S. Venkateswaran, J. Moore, and A. Krueger, 1961, in the *Journal of Geophysical Research*) but failed to produce good results because at the high altitude of the satellite the entire ozone layer was as large as the solar disk.

The first experimental active ozone sensor was flown aboard the USAF satellite SAMOS-9 (1962 launch). Its single-channel UV radiometer used the solar occultation limb technique. Ariel-2 (1964 launch; e.g. Poland *Scott* 1468, from 1966) did much the same thing, with somewhat different instruments.

Next came a new technique using backscattered radiation (radiation moving in a direction at least 90 degrees different from its initial direction). Backscattered UV (BUV) was the UV component of sunlight that had penetrated downward to the lower atmosphere, and even as far the surface, before being scattered and reflected back upward. A downward-looking sensor could measure the BUV spectrum which, combined with certain other information including the incident solar UV and the surface reflectance, would provide an ozone profile (i.e. the vertical distribution of ozone above a point). The technique was extended in 1967 (J. Dave and C. Mateer, 1967, in the *Journal of the Atmospheric Sciences*) to allow the calculation of total column ozone as well, and that extension was first used in 1970 on Nimbus-4 (see below).

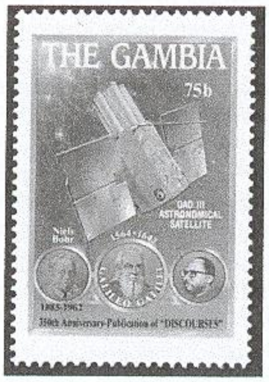
The USSR tested the first space-based BUV spectrophotometer aboard Kosmos-45 (1964 launch). It was an experimental weather satellite. That BUV sensor was also flown on the experimental





weather satellites Kosmos-65 (1965 launch), Kosmos-92 (1965 launch), and Kosmos-122 (1966 launch). A launch cover from Tartu, Estonia nicely shows Kosmos-122, and Laos *Scott* 784 (from 1987) shows a Kosmos satellite that is clearly one of this group.

The first US BUV instrument was a single-channel radiometer that looked downward at 30 degrees to the left of nadir. It was flown aboard the USAF satellite OV1-1 (1965 launch). Similar early American BUV measurements were made by instruments on OV1-10 (1966 launch) and OGO-4 (1967 launch; e.g. Sierra Leone *Scott* 1069i).



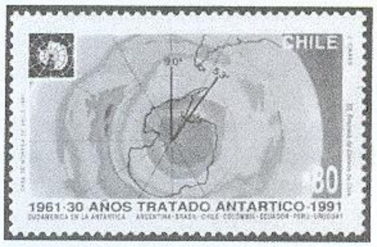
Starlight limb occultation was attempted with a UV telescope and spectrophotometer aboard OAO-2 (1968 launch; e.g. Sharjah *Scott* 42, from 1964, issued in advance of the launch) and OAO-3 (1972 launch; e.g. Gambia *Scott* 799, from 1988). In the OAO-3 experiment, β Centauri was the target star. Neither experiment produced credible results. To the authors' knowledge, starlight occultation was not again used until 2002, with Envisat (see below).

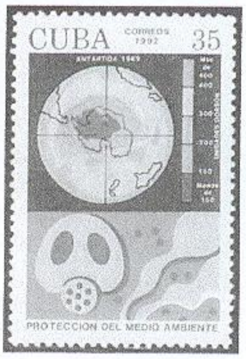
Another advance in ozone remote sensing techniques came with the InfraRed Interferometer Spectrometer (IRIS) that flew on Nimbus-3 (1969 launch; e.g. Zambia *Scott* 61, from 1970). The IRIS looked downward toward the nadir and measured the thermal emissions of the Earth and atmosphere in certain wavelength bands, including the 9.6 µm ozone absorption band. This type of instrument is known in general as an atmospheric sounder. It provided ozone profiles. The technique had weaknesses, however. IRIS was limited to cloud-free regions with low surface emissivity. Furthermore, the "contribution function" necessary for the calculations was limited to the upper tropospheric and lower stratospheric regions, so that ozone in the rest of the column was not sensed.

Both a BUV spectrometer and an IRIS were aboard Nimbus-4 (1970 launch). Many stamps show generic Nimbus satellites (e.g. China-Taiwan *Scott* 1652, from 1970; Dominica *Scott* 355, from 1973; and Portugal *Scott* 1115, from 1970) but none refer specifically to Nimbus-4. However, launch covers are also available, including one with a Sarzin cachet that mentions ozone. The BUV and IRIS sensors were nadir-viewing instruments that functioned as sounders and provided ozone profile information.

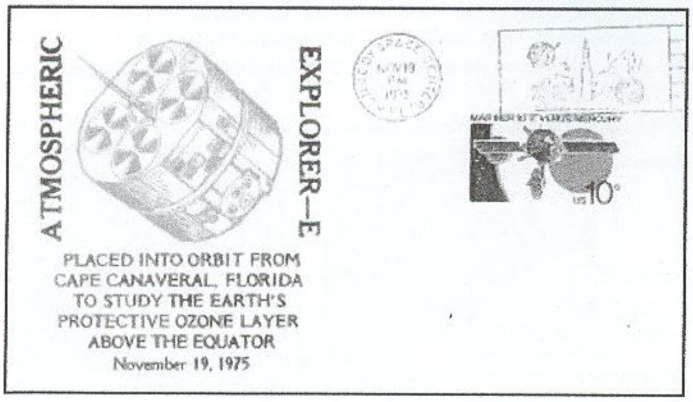
The Limb Radiance Inversion Radiometer (LRIR) was an updated IRIS designed for limb scanning. It flew aboard Nimbus-6 (1975 launch).

Nimbus-7 (1978 launch) was one of the most successful remote sensing satellites ever, with 14.5 years of data, until 1993! It carried three ozone-monitoring instruments. The Limb Infrared Monitor of the Stratosphere (LIMS) was a limb scanning sensor designed to provide ozone profiles by measuring IR radiation coming from the limb. LIMS collected data for 9 months until the cryogens were exhausted. The Solar Backscatter Ultraviolet Radiometer (SBUV) was an updated Nimbus-4 BUV instrument. The Total Ozone Mapping Spectrometer (TOMS) was a new instrument designed to map the spatial distribution of total column ozone. Nimbus-7 carried the first version of this sensor (TOMS-1) which shared some components with the SBUV sensor. With all this capability, Nimbus-7 was the most advanced ozone monitoring instrument of its time. After the discovery of the Antarctic ozone hole in the mid-1980s, remote-sensing satellites with ozone sensors paid special attention to the South Polar area, and the resulting images were dramatic.

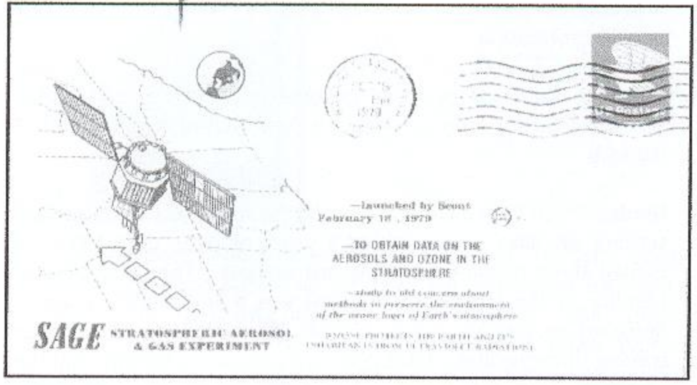




Within a few years, some postage stamps included depictions of the hole (e.g. Chile *Scott* 974, from 1991; and Cuba *Scott* 3391, from 1992). The images of total ozone on those stamps were based on information from Nimbus-7 TOMS. The TOMS-1 aboard this satellite provided a long and complete dataset: a daily worldwide map of total ozone from 1 November 1978 to 6 May 1993.



Other ozone monitoring satellites were also launched in the 1970s. AE-5 (AE-E, Explorer-55) (1975 launch) carried the engineering model Nimbus-4 BUV sensor in a low inclination orbit. A launch cover with a Centennial cachet refers to studying "the protective ozone layer" as its mission. AEM-2 (AEM-B, Explorer-60) (1979 launch) carried the first version of a new instrument, the Stratospheric Aerosol and Gas Experiment (SAGE-1). As seen in a launch cover with a Space Voyage cachet, its mission was to "obtain data on aerosols and ozone in the stratosphere". No stamps are known to show these satellites.



Four Defense Meteorological Satellite Program (DMSP) satellites (DMSP-5D1-F1 through F4) were successfully launched between 1976 and 1979 (the F5 launch failed in 1980). These satellites carried a multichannel filter radiometer known as the Special Sensor "H" (SSH). This instrument was an IR sounder and included a channel in the 9.6 µm ozone absorption band. No stamps are known to show these satellites but launch covers are available.

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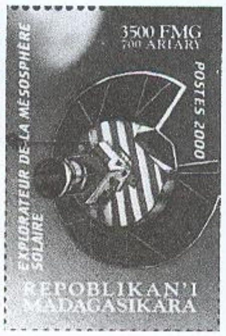
A long series of NOAA (National Oceanic and Atmospheric Administration) polar-orbiting weather satellites carried ozone monitoring instruments, starting with NOAA-6 (1979 launch) and ending with the last in the NOAA series, NOAA-19 (also known as NOAA-N Prime) (2009 launch). Many stamps show generic NOAA satellites (e.g. Malagasy *Scott* 969, from 1990) but none refer to specific members of the series, except Netherlands *Scott* B652 (from 1990) which shows a satellite image taken by NOAA-11, but does not depict the satellite itself. All the NOAA satellites carried a sounder known as the High Resolution Infrared Radiation Sounder (HIRS), versions 2 or 3 or 4. This complex instrument includes a channel in the 9.6 µm ozone absorption band and provides observations of ozone and many other atmospheric constituents. In addition, NOAA-9, 11, 13, 14, 16, 17, 18, and 19 carried the SBUV/2, an updated version of Nimbus-7's SBUV instrument. The NOAA series will be replaced in the coming years by the Joint Polar Satellite System (JPSS, formerly known as NPOESS, the National Polar Orbiting Operational Environmental Satellite System). Those satellites will carry the Ozone Mapping and Profiler Suite (OMPS), an advanced package with both a nadir viewing BUV sensor and a limb viewing UV/visible sensor that will provide detailed ozone observations.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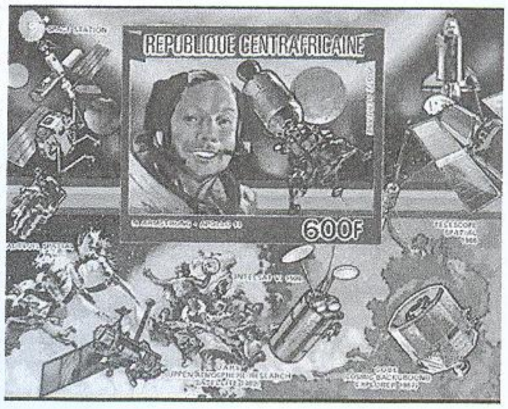
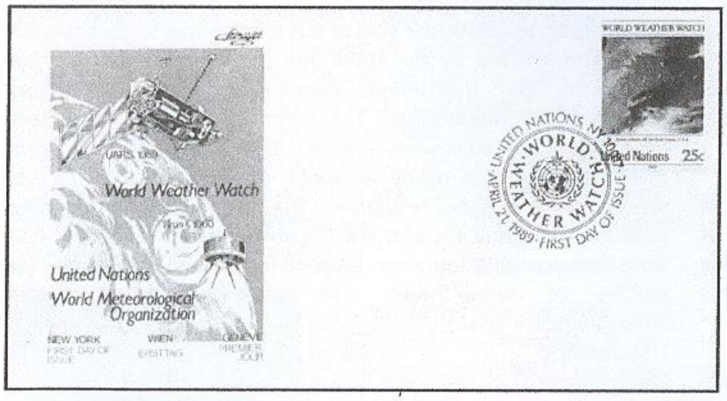
Two research satellites with ozone capabilities were launched in the 1980s. SME (Explorer-64) (1980 launch) carried solar and BUV spectrometers and an IR radiometer. Its mission was to study ozone in the upper stratosphere and the mesosphere. This satellite is nicely depicted in Malagasy *Scott* 1536d (from 2000). A launch cover with a Goddard Space Flight Centre cachet shows the satellite and also summarizes in a few words its ozone mission. The ERBS (Earth Radiation Budget Satellite, 1984 launch from Space Shuttle mission STS-41G) carried SAGE-2, an updated package from the SAGE-1 that was aboard AEM-B. Both SAGE instruments were limb scanners, and measured UV in sunlight at sunrise and sunset. One of the goals of ERBS was to measure ozone loss in the upper stratosphere. No stamps are known to show ERBS, but launch covers exist.

San Marco-D/L (also known as San Marco-5; 1988 launch) was designed to explore the relation between solar activity and phenomena in the ionosphere and thermosphere. It probably did not measure ozone, but a sister satellite, San Marco-D/M, was designed to monitor cloud cover and ozone. Unfortunately, this satellite was cancelled.



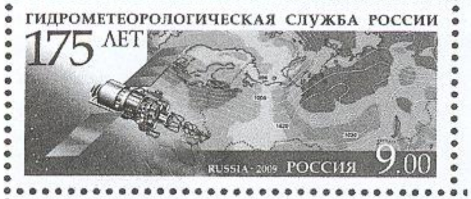
The UARS (Upper Atmosphere Research Satellite) was launched by the shuttle STS-48 in 1991. It was the first satellite of NASA's Mission to Planet Earth series, and carried a wide variety of sensors. The Cryogenic Limb Array Etalon Spectrometer (CLAES) measured vertical profiles of ozone. The Improved Stratospheric and Mesospheric Sounder (ISAMS) in conjunction with the Halogen Occultation Experiment (HALOE) provided information on the formation and destruction of ozone. The Solar UV Spectral Irradiance Monitor (SUSIM) and the Microwave Limb Sounder (MLS) also made ozone measurements. Finally, the Solar Stellar Comparison Experiment (SOLSTICE) measured solar UV radiation with the goal of determining to what degree solar cycles affect stratospheric ozone and in particular the ozone hole. UARS is nicely depicted in the lower left margin of Central African Republic *Scott* 663 (a souvenir sheet of 1, from 1984) and in the cachet of



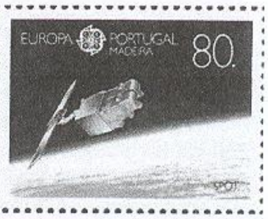
a FDC of United Nations *Scott* 550 (from 1989).

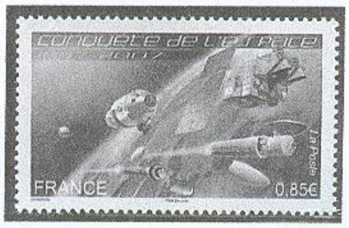
Some Space Shuttle missions also carried ozone sensors. Eight missions starting with STS-34 (in 1989) and ending with STS-72 (in 1996) carried the carried the Shuttle Solar Backscatter UV (SSBUV) radiometer in the Shuttle cargo bay. One of the goals of this instrument was to provide calibration data for the ozone measurements made by NOAA-9, NOAA-11, Nimbus-7, and the UARS. In addition, STS-45 (1992), STS-56 (1993), and STS-66 (1994) carried ATLAS-1, 2, and 3, respectively (Atmospheric Laboratory for Applications and Science). Among other things, the ATLAS package studied the chemical properties of the middle atmosphere with the goal of determining how those factors might affect ozone. Two later shuttle flights carried different instruments. SOLSE/LORE (Shuttle Ozone Limb Sounding Experiment and the Limb Ozone Retrieval Experiment) were carried by STS-87 (1997). These sensors were designed to provide both vertical and horizontal distributions of ozone through solar occultation limb scanning. The updated SOLSE-2 was carried by STS-107 in 2003. Its goal was to obtain limb data on ozone in a wide variety of conditions. Unfortunately, STS-107 was lost on re-entry.

The Russian Meteor 3-5 (Meteor-TOMS) (1991 launch), the first joint US-USSR Earth science mission, carried the engineering model Nimbus TOMS instrument (supplied by NASA) to obtain high-resolution maps of global total ozone. This mission extended the 14.5 year Nimbus TOMS record of global ozone by three more years while three new TOMS instruments were being built. A more modern Meteor design, Meteor-3M (originally Meteor-3M-1) was launched in 2001. It carried the SAGE-3 instrument, a limb scanner that was an update of the SAGE-2 flown on the ERBS. One of its goals was to study the processes leading to ozone depletion during the boreal winter. Its orbit was such that it could provide the necessary high latitude coverage. Furthermore, in this way it could complement the middle and low latitude coverage previously provided by SAGE-2 and ERBS. Russia *Scott* 7140 (from 2009) nicely depicts Meteor-3M. It was originally hoped to launch a companion satellite, Meteor-3M-2, with another SAGE-3 instrument, but those plans were shelved and the satellite was cancelled in 1999. Meteor-M1, the first of the new generation of Meteor weather satellites, was launched in 2009. It is depicted on at least one Russian launch cover. It has several instruments including an imager/sounder identified by the acronym MTVZA, and what is probably the first version of a new IR sounder (IRFS-1). These sensors can measure ozone and many other atmospheric constituents. The next satellite in the series, Meteor-M2, is scheduled for a future launch. It should have the same instrument suite, except for an apparent updated IR sounder (IRFS-2).



Also in the 1990s, some ozone monitoring satellites from Europe and other countries began to appear. SPOT-3, a French satellite, was launched in 1993. It measured ozone profiles with a package known as the Polar Ozone and Aerosol Measurement - 2 (POAM-2), which used the solar occultation limb scanning technique. SPOT-4 followed in 1998, with the updated POAM-3. No stamps are known that specifically identify SPOT-3 or SPOT-4. Many (e.g. Portugal Madeira *Scott* 152a, from 1991) show a satellite that can be identified as SPOT-1 or -2 or -3 (they were all very similar). SPOT-4 and SPOT-5 had an updated design, and again it is impossible to differentiate between them on stamps. France *Scott* 3358 (from 2007) is an example of a stamp that depicts either SPOT-4 or SPOT-5. Some launch covers are also available for these satellites.

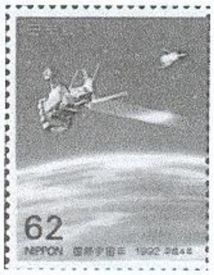




ERS-2 (Environmental Remote Sensing - 2, 1995 launch) was the first ESA (European Space Agency) satellite to carry ozone measuring equipment. Known as the Global Ozone Monitoring Experiment - 1 (GOME-1), this instrument used the BUV technique and differential optical absorption spectroscopy to provide continuous measurements of global ozone profiles and total column ozone. Quite a few stamps show ERS-1 but none are known that specifically refer to ERS-2. Launch covers and other cachet covers for ERS-2 are available.

TechSat-1A, a microsatellite from Israel, failed to reach orbit in 1995. It carried the Ozone Meter - 2 (OM-2) SBUV radiometer. The replacement satellite, TechSat-1B, was launched in 1998 with the same instrument. There exist at least two launch covers for TechSat-1B which nicely depict the satellite. A Chilean microsatellite, FASat-Alfa, was launched from Russia in 1995 but was lost in space when it failed to separate from the main payload. It carried the Ozone Layer Monitoring Experiment (OLME) and was designed to monitor the destruction of ozone above Chile. FASat-Bravo, the replacement satellite with the same payload, was successfully launched in 1998.

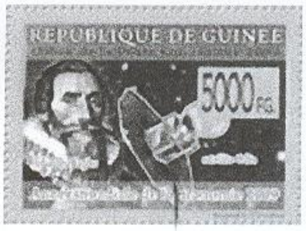
TOMS-EP (Earth Probe) (with the TOMS-3 instrument) and the Japanese ADEOS-1 (Advanced Earth Observing Satellite), with the TOMS-4 and the limb sounder ILAS (Improved Limb Atmospheric Spectrometer), both launched in 1996, were designed to continue the global ozone mapping of Nimbus-7 and Meteor-3-5. TOMS-EP was originally intended to follow Meteor-3-5 in 1994 but was delayed by rocket problems until 1996. This resulted in an 18 month gap in global total ozone coverage. The orbits of TOMS-EP and ADEOS-1 were arranged for complementary coverage, but ADEOS-1 failed prematurely, so the TOMS-EP orbital altitude was increased to enlarge the coverage area. No stamps are known to show TOMS-EP, but a few (e.g. Japan *Scott* 2134, from 1992) depict ADEOS-1. The satellite QuikTOMS, with the TOMS-5 instrument, was to replace missing TOMS coverage due to the failure of ADEOS-1 and



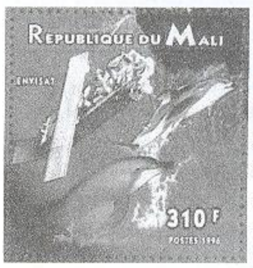
the cancellation of Meteor-3M-2. Its mission was to monitor global ozone levels with emphasis on the Arctic and Antarctic. Unfortunately, the launch (in 2001) on a Taurus rocket failed. ADEOS-2 (2002 launch) did not carry a TOMS instrument, but did carry an updated ILAS known as ILAS-2.

MSX (Midcourse Space Experiment, launched in 1996) was a satellite with multiple goals including the observation of ozone. It carried the UVISI (Ultraviolet and Visible Imager and Spectrographic Imager). This was apparently a limb sounding instrument. No covers or stamps for it are known.

STEP-4 (Space Test Experimental Program 4, launched in 1997) was a Department of Defense satellite with instruments including the OOAM (Orbiting Ozone and Aerosol Measurement). Unfortunately, its solar panels failed to deploy and contact was lost. No stamps or covers are known for this satellite.



Odin (2001 launch) was a Swedish satellite that carried the Canadian Space Agency's OSIRIS instrument (Optical Spectrograph and InfraRed Imager System). This instrument was designed to measure ozone distribution in the mesosphere. A second instrument, the SMR (Sub-mm Radiometer) measured ozone and other gases in the stratosphere. Odin is depicted in Guinea Republic *Michel* 5840 (from 2008).



Envisat (2001 launch) was a large, complex European Earth-observation satellite with instruments to measure the properties of land, ocean, ice, and the atmosphere. For ozone work, it carried the Global Ozone Monitoring by Occultation of Stars (GOMOS) instrument which was designed to produce high-resolution ozone profiles and accurate estimates of how ozone changes in time. Such detailed observations are necessary for an understanding of ozone chemistry and also for the validation of ozone models. Envisat appears on a few stamps, including Mali *Scott* 847c (from 1996).

SORCE (the Solar Radiation and Climate Experiment satellite, launched in 2003) was a NASA mission designed to study various aspects of the climate as well as ozone and UV-b radiation. It was the second satellite to carry the SOLSTICE instrument (UARS was the first). The goal of this instrument was to provide insight into the question of how solar cycles affect stratospheric ozone and the ozone hole and to provide a dataset that would merge into that of UARS and carry on into the future. No stamps are known to show SORCE, but launch covers with nice depictions exist.

SciSat (2003 launch) was a Canadian satellite with the Atmospheric Chemistry Experiment – Fourier Transform Spectrometer (ACE-FTS). It made detailed observations of various upper atmospheric chemicals with the goal of improving the understanding of chemical and dynamical processes that cause the destruction and creation of stratospheric ozone, with particular emphasis on the high northern latitudes including Canada and the polar region. Launch covers are available.

EOS-Aura (2004 launch, formerly known as EOS-Chem) is a member of the Earth Observing System constellation of satellites known as the "A-train". Its multiple sensors were for climate, air quality, and ozone observations in the troposphere as well as the stratosphere. With respect to ozone, the goal of this mission was to continue the observations made by the UARS and the various satellites that carried the TOMS instrument. Aura carried several instruments used in ozone monitoring. The Ozone Monitoring Instrument (OMI) used the downward-looking SBUV technique to provide global total column ozone amounts, as did the earlier TOMS sensors, but at a higher resolution. The High Resolution Dynamics Limb Sounder (HIRDLS) and the Microwave Limb Sounder (MLS) were limb-scanning sounders designed to produce high-resolution profiles of ozone and other atmospheric gases. The Tropospheric Emission Spectrometer (TES) was both a limb and a nadir spectrometer that, in conjunction with the OMI, produced tropospheric ozone profiles and data on ozone production and transport in that atmospheric layer. EOS-Aura, along with some other members of the A-train, is depicted in Sierra Leone *Scott* 2871d (from 2006) and Tanzania *Scott* 2444 (a souvenir sheet of 1, from 2007).

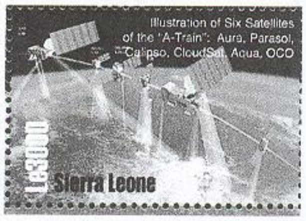


Illustration of Six Satellites of the "A-Train": Aura, Parasol, Calipso, CloudSat, Aqua, OCO
Le5000
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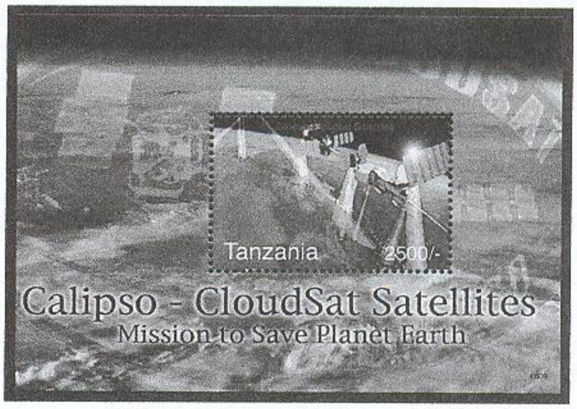
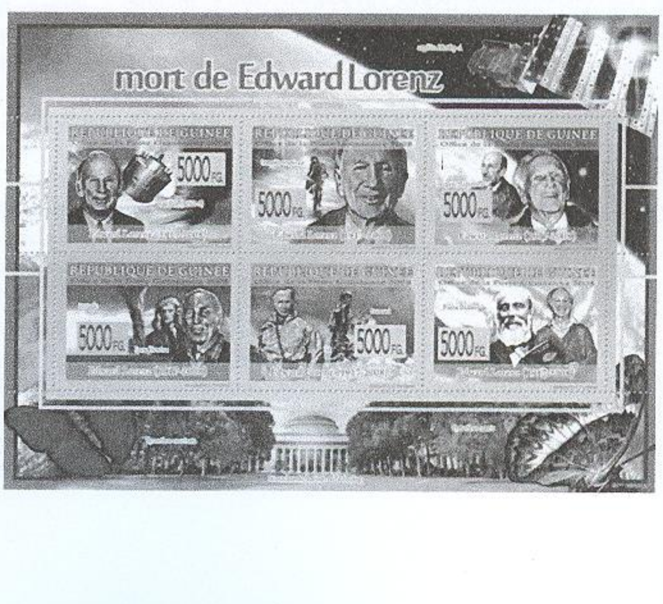


MetOp-A (2006 launch) was the first European operational polar-orbiting weather satellite. For ozone measurements, it carried an update of the GOME-1 instrument that flew aboard ERS-2. GOME-2 in MetOp-A was a BUV spectrometer that used differential optical absorption spectroscopy to provide global total ozone data. The satellite also carried HIRS/4 – the same instrument found in many of the recent NOAA satellites. It is a sounder with a channel in the 9.6 µm ozone absorption band that provides profiles of ozone as well as many other atmospheric constituents. MetOp-A is nicely depicted in the upper-right margin of a sheet of 6 stamps (*Michel* 5873-5878, from 2008) issued by the Republic of Guinea. MetOp-B and MetOp-C, with the same instrumentation, are scheduled for launch in the coming years.



The only Chinese satellites known to carry ozone-measuring instruments are the FY-3 series of polar orbiters. FY-3A (2008 launch) and FY-3B (2010 launch) carried the TOM (Total Ozone Mapper, also referred to as the TOU, Total Ozone Unit), a six channel spectrometer similar to the earlier TOMS instruments, and the SBUS (Solar Backscattering UV Sounder), an ozone profiler that uses the SBUV technique. FY-3C, yet to be launched, is expected to carry the same instruments. No stamps are known to show the FY-3 satellites, but launch covers are available.

The Japanese Greenhouse Gases Observing Satellite (GOSAT, formerly called GCOM-A1 or ADEOS-3) was launched in January 2009. The Ozone Dynamics UV Spectrometer (ODUS) was originally planned for this satellite, but was not used. Instead, GOSAT carries the TANSO-FTS (Thermal and Near-IR Sensor for Carbon Observation – Fourier Transform Spectrometer). This instrument is similar to the ozone-monitoring ACE-FTS carried by SciSat. However, the main goal of the mission was to make detailed observations of the principal greenhouse gases.

The French microsatellite Picard (2010 launch) was designed to make solar measurements and help determine the effect of solar forcing on the Earth's climate, but also carried the PREMOS (PRecision Monitor for OScillation measurement), a set of three photometers that measured solar spectral irradiance in five channels: one visible, two IR, and two in the UV in wavelengths useful for ozone photochemistry. The goal of this limb scanner was to study ozone formation and destruction. Launch covers are available.

In the not-too-distant future, the JPSS series of polar-orbiting weather satellites, along with Meteor-M2, FY-3C, MetOp-B, and MetOp-C (mentioned above) will carry ozone instruments.

Other future satellites will also carry ozone monitoring equipment. The Citizen Explorer Satellite CX-1 is a microsatellite developed in Colorado with the goal of producing a global environmental science database. It carries a spectrophotometer that will measure UV-b radiation and a photometer to measure surface reflectance. These instruments will provide data about stratospheric ozone. The mission concept is that those data would be sent directly to schools, where the students themselves would learn how to do the analysis. CX-1 is still waiting for a launch slot.

The Deep Space Climate Observatory DSCOVR (proposed by Al Gore in 1998, developed under the name Triana, and then mothballed) has apparently gained a new lease on life. It was originally designed with a full suite of climate-observing instruments that would observe the Earth while parked at the Lagrange L1 point. Part of the initial design included ozone and UV sensors. Recent development of the satellite apparently emphasizes space environment sensors, and there has been argument about whether or not the climate package, which is already built, should even be included. It is uncertain whether or not DISCOVR will be launched, and if so whether or not it will include the climate package. If it passes all those hurdles, it should be able to provide a unique climate dataset which will include information on ozone.

The Meteosat Third Generation (MTG) satellites (four in total), tentatively planned for the 2016 to 2030 timeframe, will include a variety of advanced instrumentation including an InfraRed Sounder (IRS) capable of measuring ozone along with many other atmospheric constituents. Finally, two MTG sounding mission satellites (MTG-S) are tentatively planned for the 2018 to 2026 timeframe. They will carry the IRS and the UVN (UV Visible and Near -IR sounder) for various atmospheric measurements including ozone. These MTG satellites will be renamed with a 'Meteosat' name when they become operational.

Some readers may be interested to note that at least three satellites that were sent to Mars carried ozone-measuring instruments, but they are outside the purview of this article.

Readers who are interested in the satellites mentioned in this article (or many others) in a philatelic context are invited to consult the authors' Un-manned Satellite Philately website at http://rammb.cira.colostate.edu/dev/hillger/satellites.htm.

Summary tables of the ozone satellites and instruments discussed in this article are part of that website and can be found at http://rammb.cira.colostate.edu/dev/hillger/ozone-monitoring.htm. A page devoted to ozone-related stamps in general is available at http://rammb.cira.colostate.edu/dev/hillger/ozone.htm which is part of the authors' Weather and Climate Philately website at http://rammb.cira.colostate.edu/dev/hillger/weather.htm.

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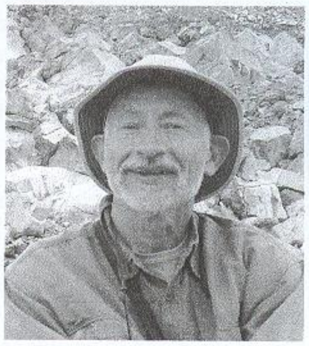

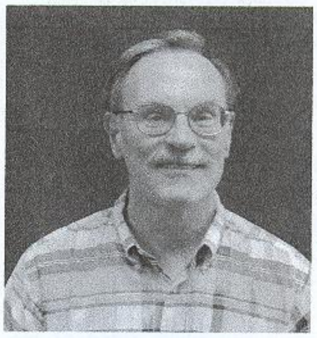

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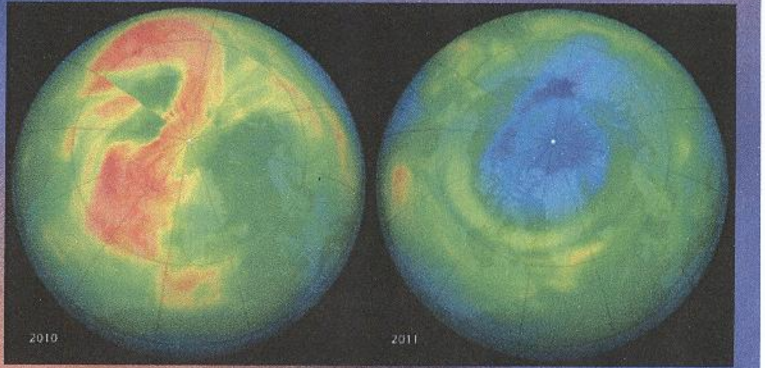
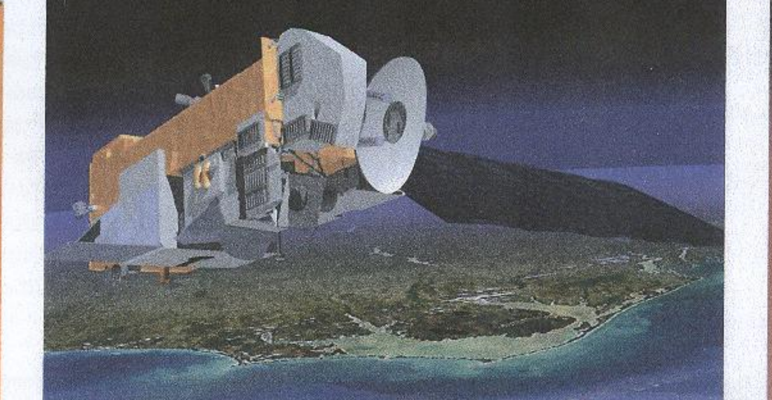
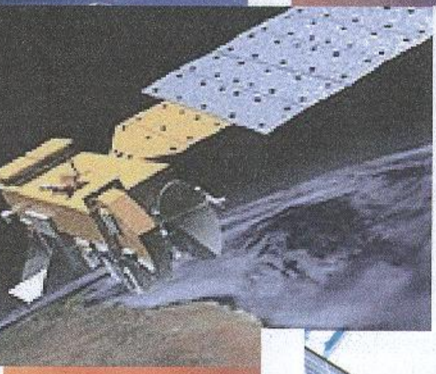
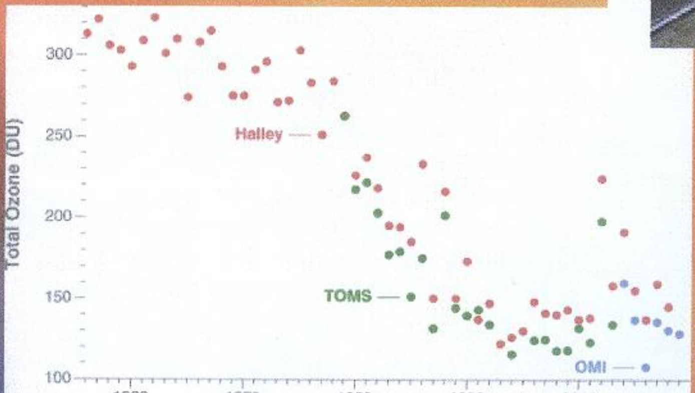




OZONE MONITORING





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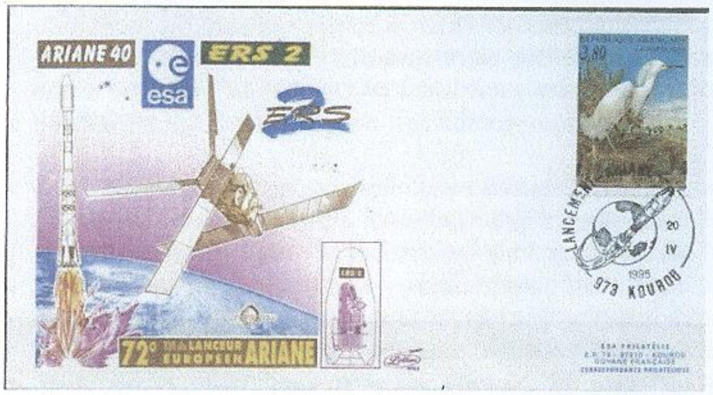

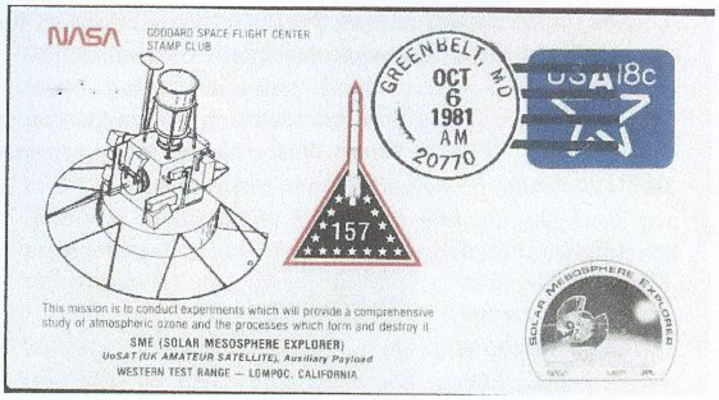
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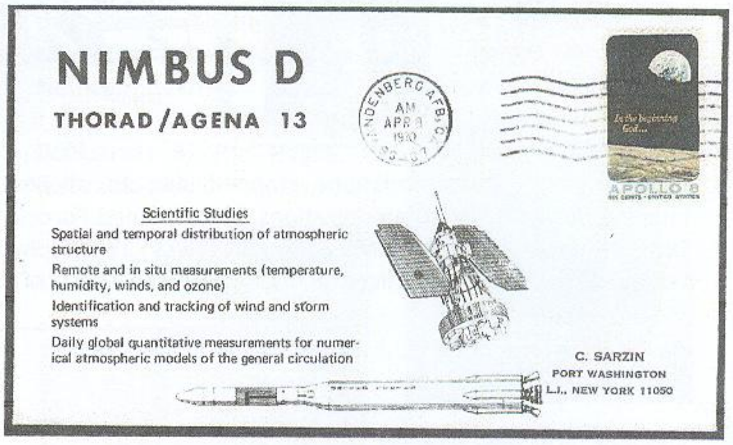
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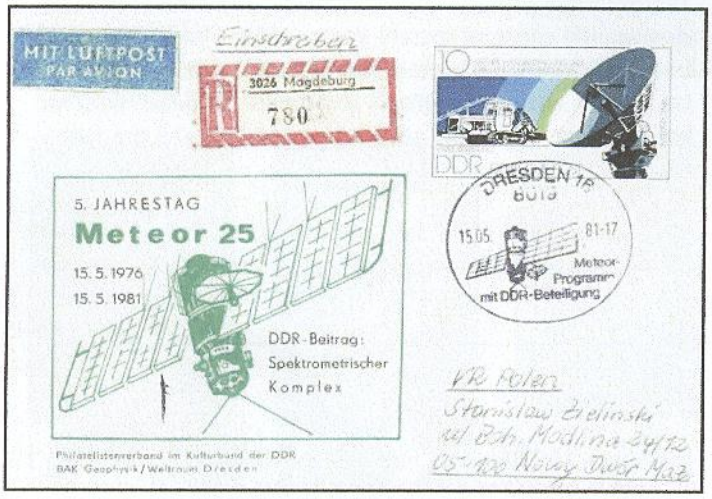

A Brief History of Ozone-Monitoring Satellites and Instruments

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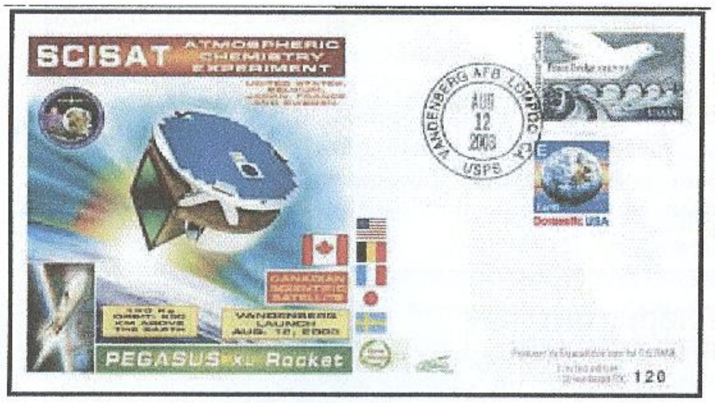
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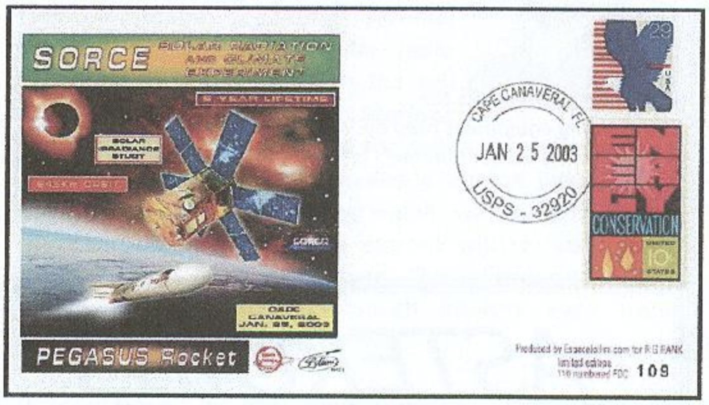

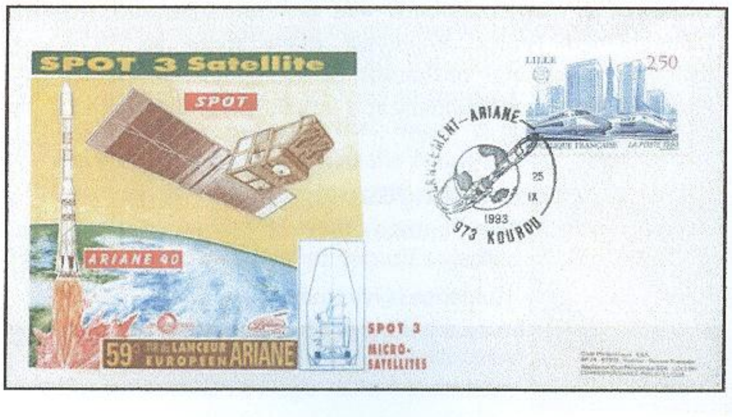

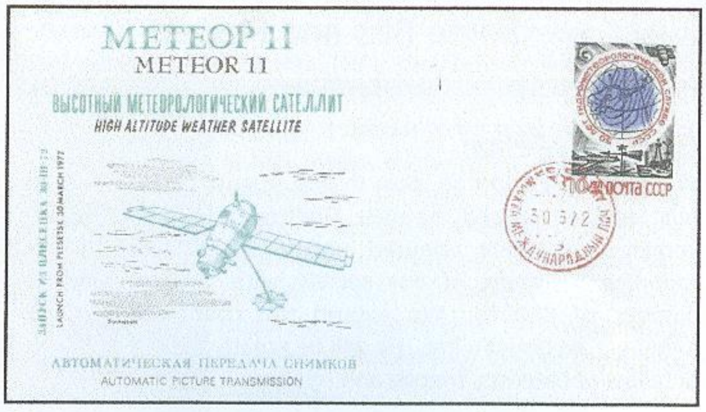
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